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1. Titles must have a length not exceeding 50 characters and spaces.

2. A summary of approximately 50 words must accompany the paper, a 300-word synopsis must precede it, and a set of conclusions must end it.

3. The manuscript (an original ribbon copy and two duplicate copies) should be double-spaced on one side of 8½-inch by 11-inch paper. Three copies of all illustrations, tables, etc., must be included.

4. The author's full name, Society membership grade, and footnote reference stating present employment must appear on the first page of the paper.

5. Mathematics are recomposed from the copy that is submitted. Because of this, it is necessary that letters be drawn carefully, and that special symbols be properly identified. The letter symbols used should be defined where they first appear, in the illustrations or in the text, and arranged alphabetically in an Appendix.

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9. Technical papers intended for publication must be written in the third person.

10. The author should distinguish between a list of "Reading References" and a "Bibliography," which would encompass the subject of his paper.

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

THE CIVIL ENGINEER AND URBAN TRANSPORTATION[a]

By Jack B. Blackburn,[1] M. ASCE

SYNOPSIS

The growing transportation problem in urban areas is clearly evident in the historical trends and in the projections of every measurable element of the urban transportation system. The principal problems which stand in the way of the more rapid expansion of transportation facilities in urban areas are no longer those of a technological nature, but rather are related to the need for adequate financing. The civil engineer, charged with the ultimate responsibility for the satisfactory performance of transportation facilities, must establish himself in a role of leadership in the conception, design, financing, construction, and operation of transportation facilities. As a leader in the solution of the transportation problems of the future, the civil engineer must improve the tenchology associated with transportation planning, and learn more about financing and how to motivate the general public. He must work for an improvement in the stature of the American Society of Civil Engineering (ASCE) as a recognized medium of expression of advanced thinking and research findings, and give serious thought to the role of courses in transportation and urban planning in the civil engineering curriculum and the importance such courses

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a Presented at the April 1961 ASCE Convention in Phoenix, Ariz.

1 Dir. Arizona Transp. and Traffic Inst., Univ. of Arizona.

play in training the civil engineer in the creation and accomplishment of urban transportation facilities.

As urban America is viewed, a rather disconcerting panorama is spread before us. A rapid increase in the total population is seen, and an even more rapid increase in the suburban population, a steady rise in automobile registration and usage, and an equally steady decline in transit usage. All this has led to an increase in the cost of municipal services, high levels of congestion and accidents on our street systems, and chronic financing problems for transportation systems.

To appreciate this panorama it is necessary to view it in terms of historical trends and the projections of these trends into the future. In the first half of the twentieth century, the total population of the United States doubled from 75,000,000 to 150,000,000, while at the same time the urban population tripled from 30,000,000 to 90,000,000. A conservative projection of these trends for the last half of the twentieth century indicates that by the year 2000 the total population will have increased by a factor of 1.8, and will total 275,000,000. During this same time, all indications are that the urban population will increase by at least a factor of 2.25 to a total of 206,000,000. Stated in a different way, the urban population was approximately 40% of the total population in 1900, 60% in 1950, and will be at least 75% by the year 2000.

Because of the relative attractiveness of suburban living, population is growing at a much more rapid rate outside the central city. This is evident from a comparison of 1950 and 1960 population statistics.[2] In every urban area with a 1960 population of 1,500,000,000 or more, the central city actually lost population between 1950 and 1960. The single exception was the Los Angeles-Long Beach metropolitan area. While a loss in population for these central cities ranged from 5% to 15%, the increases in population outside the central city, with one or two exceptions, ranged from 50% to 80%.

Other historical trends of interest to the civil engineer are those in vehicle registration and vehicle ownership. In 1900 there were 8000 privately-owned automobiles, or 9500 persons for each automobile. By 1950 there were over 40,000,000 privately-owned automobiles, or 3.75 persons per vehicle. Projections of these figures indicate that, by the year 2000, there will be approximately 180,000,000 privately-owned automobiles in the United States, or 1 automobile for every 1.5 persons. This is 4-1/2 times the number of privately-owned automobiles registered in the year 1950.

Other statistics of interest are the percentages of households which own automobiles. In metropolitan areas of 500,000 or more, approximately 60% of the households located in the central city own at least one automobile; in areas with less than 500,000 population, approximately 80% own at least one automobile; in the suburbs of metropolitan areas, approximately 85% to 90% own at least one automobile.[3]

From the preceding it is clear that vehicle ownership is increasing at a more rapid rate than the population. A logical conclusion is that the rapid rise in vehicle ownership would result in a greater use of the automobile as a mode

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2 "1950-1960 Population Shift Poses Transportation Problem," by Thomas Conway, Jr., Traffic Quarterly, January, 1961.

3 "Automobile Facts and Figures," Automobile Mfrs. Assoc., 1961, p. 34.

of travel. This conclusion is borne out by observations made in Chicago over a 30-yr period.[4] With the number of person trips made to and from the Chicago Loop remaining fairly constant between 1,600,000 and 1,700,000, the number of trips made by automobile doubled from 19% to 38%. The reverse trend was experienced on bus and street car travel, with the total being reduced from 39% to 19%. Travel on rapid transit constituted 29% of the total trips at the beginning of the period and, after a slump in the 1930's, had again risen to 29% of the total by the end of the period. Travel on the suburban railroads during the period increased slightly from 13% to 16%.

The dominance of the automobile as the preferred mode of travel is further emphasized by data from the Chicago Area Transportation Survey[5] which show that 77% of all trips in the Chicago area were made by automobile, only 5% by rapid transit and suburban railroad combined, and 18% by bus. Detailed analyses of data from origin-destination traffic surveys lend further emphasis to the growing problem of automobile travel. Data from the Detroit Area Survey,[6] made in 1953, revealed travel patterns typical of those from other surveys. For instance, as the average number of cars per household increased from 0.2 to 1.8, the average number of weekday trips per household increased from 2.0 to 11.0. It was also revealed that as the distance from the household to the central business district increased from less than 3 miles to over 12 miles, the average number of weekday trips per household increased from 3.5 to 8.0. As the family income increased from the lowest 10% bracket to the highest 10% bracket, the average number of weekday trips per household increased from 2.8 to 8.1. Data of particular interest to the land-use planner, providing valuable background information for locational studies as developed from the Chicago Area Transportation Study,[7] relate airline trip length to trip purpose. Approximately 35% of all trips made in the Chicago area were less than 2 miles in length; 60% were less than 4 miles, 85% less than 8 miles, and 95% less than 12 miles.

When all the foregoing statistics are reviewed and their interactions evaluated, a clear conception is obtained of the physical setting of the urban area and of some of the factors which contribute to the transportation and land use planning problems that exist at the present time. It is clear that the urban area population is expanding at a rapid rate, in fact at a more rapid rate than for the nation as a whole. This increase in population is taking place in outlying suburbs rather than in the central city. People living in the suburbs make substantially more trips per household than people living closer to the center of the city; the majority of all trips are made by automobile. Finally, the airline trip lengths, for trips made by people living in the suburbs, are substantially less than the airline distance to the central business district. The consequences of people's living and travel habits have contributed to the emergence of blighted areas and serious traffic congestion in the central cities of every large urban area in the United States.

Certainly the problems which have been created by the rapid expansion of urban areas have been widely recognized and studied. How to accomplish the necessary coordination between the urban planner and the highway planner was

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4 "Cordon Count Data for the Central Business District," Bur. of Street Traffic, Chicago, Ill., 1957.

5 CATS Research News, Vol. 2, No. 4, February 28, 1958.

6 Detroit Metropolitan Area Traffic Study, 1953.

7 CATS Research News, Vol. 2, No. 8, April 25, 1958.

the subject of discussion at a National Conference on Highways and Urban Development, held at Syracuse University in October, 1958.[8] This conference was sponsored by the Joint Committee on Highways of the American Municipal Association, American Association of State Highway Officials, and by the Committee on Urban Research of the Highway Research Board, with physical facilities provided by Syracuse University at the Sagamore Center, and financial and editorial assistance provided by the Automotive Safety Foundation. The conference was attended by highway engineers and urban planners representing all levels of government as well as universities, various professional associations, consultants, and representatives of private business. This conference emphasized the high degree of coordination required between local and state agencies in the accomplishment of transportation planning objectives and urban planning objectives, and how these sets of objectives can be made to complement rather than to contradict one another.

Another significant development, designed to help solve transportation planning problems in the United States, was the formation of the National Committee on Urban Transportation in May, 1954. This committee was originally composed of representatives of six national organizations, namely, the International City Managers' Association, the American Municipal Association, American Public Works Association, Municipal Finance Officers' Association, American Society of Planning Officials and the National Institute of Municipal Law Officers. The Bureau of Public Roads accepted membership shortly after the committee was organized, and in May, 1956, the National Association of County Officials and the Canadian Federation of Mayors and Municipalities became members.[9] By 1958, the committee had developed a set of procedure manuals for evaluating deficiencies, for projecting future needs, and for the formulation of realistic transportation which had been tested in seven pilot cities, including San Diego, Calif., Phoenix, Ariz., Albuquerque, N. M., Detroit, Mich., Pocatello, Idaho, Oak Park, Ill., and Syracuse, N. Y.[10] The significance of these publications is that planners have available a complete set of carefully organized and tested procedures to guide them in developing their own transportation planning program.

In August, 1960, the National Academy of Sciences sponsored a Conference on Transportation Research at Woods Hole, Mass. This conference, financed by the National Science Foundation, brought together engineers, social scientists, economists, urban planners, and lawyers "to review the nature and ramifications of transportation activities in the United States, and to prepare suggestions for improving national capabilities, through research, for dealing with transport problems."[11] This conference attributed the current transportation problem in part to "outmoded, ill advised, or imbalanced public policies, inadequate or spotty research effort, too narrow or biased consideration of transport issues and solutions, and shortcomings of present approaches to transport

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8 "Guidelines for Action," by Joint Committee on Highways of the Amer. Munic. Assn., AASHO, Committee on Urban Research, Highway Research Bd., Sagamore Conf. on Highways and Urban Development, Syracuse Univ., October, 1958.

9 "The Highway Engineer and the National Committee on Urban Transportation," by Jack Berman, Traffic Engineering, March, 1959.

10 "Better Transportation for Your City," by the Natl. Comm. on Urban Transp., Pub. Admin. Service, Chicago, Ill., 1958.

11 "Conference on Transportation Research," Report of Study Group, Natl. Academy of Sciences, Washington, D. C., 1960.

planning and operation." It was pointed out that research effort was needed to improve the technology, the environment, and the conduct of transportation, and that additional basic data were needed from which to make more intelligent transportation planning decisions. Finally, means for the education and training of those who will have future responsibilities for the formulation of transportation policy were explored.

Specific signs of coordination among various agencies of the federal government, in the solution of transportation and urban planning problems, were evident in the recent announcement of the formation of a steering committee from the Urban Renewal Administration and the Bureau of Public Roads for the joint planning of highways and urban redevelopment in metropolitan areas.[12] Regional committees made up of representatives of both agencies have already been formed to cooperate with state and local agencies in the conduct of local planning and development. A series of regional meetings has been scheduled for Philadelphia, Fort Worth, Chicago and San Francisco.

While national conferences, participated in by recognized authorites in transportation and urban planning, have made important contributions to the overall shaping of transportation and urban area planning policies, much factual information has been developed from transportation studies such as those made in Detroit, Chicago, Washington, D. C., Los Angeles, San Francisco, St. Louis, San Diego, Phoenix, and many other cities. A significant contribution to the inter-relationships of land use and transportation is contained in a report of the American Institute of Planners.[13] This report summarizes much of what has been learned about the influence of land use characteristics on trip generation from analyses of the data from transportation studies noted previously.

In the foregoing, there is ample evidence that a real problem exists in providing adequate transportation facilities for urban areas, that the problem is growing more serious at an alarming rate, and that a great deal of factual information has been gathered that forms the basis for enlightened transportation planning and policy decisions. The implementation of these transportation planning and policy decisions has led to the realization that the solution of the problem will require the outlay of enormous expenditures in the coming decade and that needed expenditures in the future will be at the same, or at an accelerated, rate.

Los Angeles, with its extensive network of freeways, because of which it is alternately referred to as "the freeway capitol of the world" and "the biggest parking lot in the world," is planning a rail rapid transit system, estimated to cost $550,000,000, to help solve a problem which freeways alone could not solve.[14] The planning stage alone for developing a balanced transportation system for the Washington, D. C. metropolitan area cost nearly $1,000,000 and required 4 yr to complete.[15] The plan calls for nearly 100 miles of rail and express bus rapid transit facilities and 330 miles of freeways. The rapid

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12 "Renewal and Roads Get Together," Engineering News Record, Mar. 23, 1961, p. 39.

13 "Land Use and Traffic Models," by Alan M. Voorhees, Journal, Amer. Inst. of Planners, (special issue), May, 1959.

14 "Modern Rapid Transit for the Los Angeles Area," by Irvan F. Mendenhall, Proceedings, 13th Annual Western Section Meeting, Inst. of Traffic Engrs., July 17-20, 1960, pp. 49-53.

15 "Transportation Plans: Washington's Next Steps," by Robert A. Keith, Bulletin 256 Urban Research 1960, Highway Research Bd., 1960.

transit system is estimated to cost $564,000,000 and the freeway and major street system is estimated to cost 1.8 billion dollars. Present federal and local financing programs fall far short of providing these sums of money by 1980. Approximately $1,000,000,000 of new financing must be provided in order to meet the transportation needs of the design year 1980.

Development of transportation facilities for the St. Louis metropolitan area is estimated to cost $840,000,000, consisting of $175,000,000 for 42 route miles of rapid transit facilities, $115,000,000 for the improvement of highway facilities and traffic control, $50,000,000 for off-street parking in the CBD fringe area, and $500,000,000 for the Missouri portion of the expressway system for the St. Louis area.[16] It is estimated that to finance the $175,000,000 rapid transit system, $10,000,000 of new financing annually will be required to provide sufficient debt coverage for the rapid transit bonds to be marketable. To obtain this additional financing, it is proposed that an annual automobile use tax of $20 be levied on every passenger automobile registered in St. Louis city or St. Louis county. A part of the automobile use tax would be used to provide the improvements in highway facilities and traffic control.

Rochester, N. Y., a city of 320,000 population, has adopted an 80 mile, $150,000,000 expressway plan, which is integrated with plans for municipal parking garages in the central business district, a $50,000,000 civic center, and improvements to the municipal airport, the water supply system, and in urban renewal and antipollution costing $50,000,000. All these improvements have come since 1955, when the city abandoned a pay-as-you-go policy and approved its first long term bond issue.[17] The costs for plans from other urban areas are equally impressive.

The steps required in providing adequate urban area transportation seem clear. They may be briefly summarized as follows:

1. Ascertain the objectives of the community in terms of desired types and levels of economic activity in which the community wishes to engage and which may reasonably be achieved.

2. Determine the employment which will be required to support the economic activity and, from the employment, obtain an estimate of the total population.

3. Determine spatial and locational requirements for each community activity. From these a comprehensive land use plan may be developed.

4. Determine the trip desires and travel patterns of the present population and, with known arrangements of future land uses and future population densities, determine the trip desires for the future design year.

5. Locate deficiencies in the existing transportation system and make the necessary improvements and additions so that the system will satisfactorily accommodate the design year trip desires.

6. Analyze alternate solutions, and determine the cost and level of service offered by each, in order to arrive at an optimum system design.

7. Gain the support of public officials and the general public by factual reporting of the existing situation, the need for improvement, and the benefits to be derived from planned improvements.

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16 "Bus Rapid Transit - St. Louis Area Plan," by R. Gilman Smith, Proceedings, 13th Annual Western Section Meeting, Inst. of Traffic Engrs., July 17-20, 1960, pp. 54-60.

17 "Rochester Brings Them Back from the Suburbs," Staff Report, Engineering News Record, McGraw-Hill Book Co., Inc., New York, February 16, 1961, p. 30.

8. Determine the most feasible method of financing the cost of improvements and assist in the preparation of a bond prospectus or in necessary legislation.

9. Carry out the final design and contract for the construction.

To better achieve the aims of the preceding steps, many improvements and new techniques must be developed. The transportation system has such a profound effect on land development that it is necessary to begin with the fundamentals of land use planning.

First, refined techniques are needed for measuring the economic base of the community and for measuring the contributions made by various types of economic activity to the economic base. The types of economic activity must be evaluated and the development of those which will help to stabilize the economy of the community must be encouraged. Second, it must be possible to predict the effect that automation will have on each type of economic activity in order to estimate accurately future employment requirements. Third, the desire for new and more spacious plant site locations in outlying areas, the desire for suburban living, and the trend toward the migration of commercial activities from the central business district to regional and community shopping centers must be taken into account.

Fourth, techniques for predicting future trip desires must be improved by the official adoption of a future land use plan that will serve to stabilize population densities and the locations of trip generators for which transportation facility requirements can be accurately predicted. In this connection, the technique of acquiring right of way 5 to 10 yr in advance of construction must be explored and the lease-back arrangements which substantially reduce right of way costs and hold land for the development of future transportation facilities. Engineers must also become familiar with the use of rural or agricultural zoning, the purchase of development rights, and the issuance of special use permits, to assure land development in accordance with the land use plan. This in turn will serve to stabilize the demand for transportation facilities.[18,19] Fifth, deficiencies in the existing transportation system must be examined in the light of improved driver performance, the improved performance and automatic control of vehicles, and the changes that may take place in the public acceptance of different modes of transportation.

Sixth, more careful consideration must be given to reasonable alternative solutions before adopting a final solution. Engineers must also be able to better assess the effects that different solutions will have on community activities where it is difficult to assign a monetary value. Seventh, engineers must become more adept in gaining public support of plans for new facilities and in promoting a public willingness to accept the responsibility of paying for them. More must be known about the contributions that can be made by history, government, anthropology, sociology, psychology, and economics, in order to obtain a better understanding of what motivates people to accomplish great feats in attaining certain goals and what causes them to lapse into a lackadaisical frame of mind when confronted with the attainment of other equally vital goals.

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18 "Open Space Control" by Erling D. Solberg, Bulletin 256 Urban Research 1960, Highway Research Bd., pp. 9-15.

19 "The Why and How of Rural Zoning," by Erling D. Solberg, Agric. Information Bulletin No. 196, U. S. Dept. of Agric., 1958.

Eighth, engineers must become better informed about methods of financing. An awareness of alternative ways of financing can many times make the difference between the realization of a complete plan and the need to sacrifice some portion of the plan in order to provide adquate debt coverage. Examples are the sale of general obligation bonds versus revenue bonds and the creation of a tax exempt, or tax supported, authority versus a tax paying authority. It must also be possible to assess the effects on the community of "pay-as-you-go" financing versus long term bond financing. Can city governments afford to obligate themselves to 20-yr or 30-yr bond financing for transportation facilities? Past performance indicates that the demands for additional new facilities will be apparent within 5 yr to 10 yr because of the rapid advances in technology and the dynamic nature of the urban community.

Ninth, engineers must learn to work among other people in the construction of transportation facilities without completely disrupting their lives. In densely populated urban areas it must be realized that dust, created by construction activity, must be controlled and that night operations of construction equipment in residential areas cannot be tolerated. On the other hand, the public must be willing to accept any increase in construction cost that is created by these restrictions. In the relocation of displaced persons, it should be an accepted community responsibility to provide new accommodations which are at least the equivalent of those that were vacated. When low income families are paid a fair market value for their property, it is often impossible for them to find new homes, equivalent to those they have been forced to vacate, for the money they have been paid.

Finally, the civil engineer, charged with the ultimate responsibility for the satisfactory performance of transportation facilities, must establish and maintain a position of leadership in the development of transportation facilities. He must be able to detect the need for new facilities and to organize for their accomplishment. He must understand and appreciate the importance of careful planning and preliminary investigations, and allow sufficient time for these phases, before beginning final design. When restrictions are placed on him that prevent him from completing preliminary investigations, he must be aware of the limitations that such restrictions place on his designs. The engineer must assess the time and cost of completing these investigations, as opposed to added increments of cost of a more conservative design necessitated by not completing them. When problems arise for which he does not have an adequate answer, he must be able to assimilate the necessary information from recent research findings, or seek the aid and advice of persons with more experience in the solution of the problem at hand.

Civil engineers must make a concerted effort to establish their Society in a role of leadership in the areas of transportation and urban planning. The needs for conferences and workshops must be anticipated and interested parties should convene as often as is necessary for the purpose of keeping the membership of the Society and others informed of the rapid advances that are taking place in developing improved urban area transportation. Others have seen the need for such action and have made important contributions with such activities as the Sagamore Conference on Highways and Urban Development, the preparation of the series of publications "Better Transportation for Your City," the publication of the report "Land Use and Traffic Models," and the Woods Hole Conference on Transportation Research. The ASCE was not repre-

sented in any of these activities, clearly indicating that the society is not regarded as a source of basic information on transportation and urban planning.

Finally, consider the question of the roles that courses related to city planning and transportation should have in civil engineering education. There is a committee on Civil Engineering Education within the Society that is charged with the responsibility for recommending the manner in which the objectives of civil engineering education can best be accomplished. It would seem appropriate for the City Planning and Highway Divisions to give joint consideration to the educational needs of these two divisions and the manner in which these needs may be satisfied within the framework of the recommendations of this committee's report.

CONCLUSIONS

As previously stated, the civil engineer is confronted with the challenge of establishing himself in a role of leadership in the conception, design, financing, construction, and operation of vast new transportation facilities to accommodate the movement of people and goods in the future. To accomplish this objective, the civil engineer must improve the technology of transportation planning, acquaint himself with the financing of multi-million dollar facilities, become more informed with the techniques of motivating people in order to gain their support and to generate a willingness to finance needed facilities, work for the greater recognition of the ASCE as a recognized medium of expression of advanced thought and research findings related to urban transportation problems, and carefully assess the educational requirements for future civil engineering graduates if they are to continue to lead in the accomplishment of adequate transportation facilities.

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Journal of the

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Proceedings of the American Society of Civil Engineers

HIGHWAY PIPELINE CROSSING PRACTICE

Progress Report
Committee on Pipeline Crossings

SYNOPSIS

The report summarizes current pipeline-crossing practice of state highway agencies, discusses the wide divergence of their practices with respect to primary specifications, analyzes the basic factors pertinent to highway requirements, and presents (in tentative form) its findings of minimum standards or rational basis for design.

INTRODUCTION

Transportation networks are growing in complexity as modern civilization expands and intensifies its organization of facilities for service and communication. Such networks are subways and pipelines below the ground, highways, railways, and waterways at the surface, ellways and pole lines above ground, and airways in space. Wherever the lines of these networks intersect, there is a crossing and, to some degree, a conflict of interest.

For crossings at grade, the major conflict is in priority, or in the continuity of traffic, but if grades are separated, the conflicts occur because of construction and maintenance operations of one network as it affects the operations and traffic of the other. Resolution of conflict is stated in easements, franchises, and encroachment permits of varying complexity and dependence on common law, statutes, ordinances, and regulatory edicts, in which the committee's interest is limited to engineering specifications.

Note.—Discussion open until February 1, 1962. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. HW 3, September, 1961.

Until recently there were few pipelines outside urban areas, where common law vested a right of occupancy of public ways in utilities serving the way or abutting property. Utilities located their facilities almost at will, closing and blocking roads and streets during initial construction and subsequent repair of underground piping and overhead wiring. It was not uncommon to see new pavements cut for pipeline trenches and scarred thereafter for many years by depressed patches of pavement over poorly compacted trench backfill.

Control began with allocation of line and grade to minimize underground conflicts. Accidental leakage or rupture of piping necessitated extended control by the addition of safety regulations. Public protest against blocking and degrading of pavements compelled the enactment and enforcement of engineering regulations. Each community had its own rules, varying widely in terms and enforcement.

Highways, at first, were rural roads with nominal improvement. The rural extentions of utility facilities seldom served the public way and almost never deserved vested rights of occupation therein. Some states conceded a free right; others charged an installation fee or annual rental. In at least one case where a highway located on an easement for highway purposes had permitted encroachment of a pipeline, the owner of the underlying fee recovered in court the value of the servient easement, on the finding that the pipeline had no vested right because it served no highway purpose.

Although legal problems of right of way at crossings are beyond the scope of committee studies, the anomalous interpretations of vested rights have been reflected in policies of different agencies for engineering requirements at crossings. Where vested rights are conceded, regulations might require pipes to be buried so deep that a utility would find it cheaper to acquire an independent easement. But if vested rights were not conceded, it was better strategy to allow cheap construction of a pipeline within the highway right of way under a revocable permit than to divert it into an independent easement just outside where it would have to be moved at highway expense when the highway was widened.

With the improvement of highways toward modern standards, several factors contributed to further modification of traditional policies inherited from practice in urban streets. Highway locations departed from lines bounding private property. Roadways widened, through deep cuts and over high fills. Roadside borrow ditches were superseded by borrows from cuts on the line or offsite pits. Now or prospectively, the highway used all of its right of way. Generally, the higher the standard of the highway, the less suitable was its right of way for parallel pipelines, and the more expensive was a pipeline crossing. Many utilities resisted the trend, exerting enough political pressure in some jurisdictions to compel acquisition of excess right of way, or to permit location of pipeline in medians. They had more success in urban and suburban areas, especially if utilities were publicly owned.

Expressways demanded still higher standards. When heavy traffic is carried at high speed, any impediment to flow may cause an accident, and any accident in such traffic may involve several vehicles colliding at high speed. Since some drivers veer outward to pass parked vehicles, parking is often restricted to emergency, and stalled vehicles are promptly towed to an exit. Hence parking of utility maintenance vehicles had to be severely restricted or forbidden, or the utility lines had to be designed for maintenance from offsite stations. This policy became widespread with development of full freeways,

and mandatory on the Interstate system. However, there is still a wide divergence of opinion on the physical means which should be required to assure enforcement of the policy.

In this report, attention will be drawn to the wide variation in engineering requirements of the several states. Geography and climate may explain some variation. Low requirements may indicate a lagging attention to a relatively minor phase of highway modernization. High requirements may have been set arbitrarily on the safe side. However, there is no assurance that average, median, or modal requirements per se are either safe or warranted. Analyses will aim at determination of a safe rational practice with a minimum of arbitrary requirements.

SURVEYS

Under date of December 4, 1956, the Subcommittee on Standardization of Highway Requirements of the Committee on Pipeline Crossings of Railroads and Highways of the Pipeline Division addressed a questionnaire to the several state highway agencies asking, inter alia, for copies of formal policy or code applicable to highway requirements for pipeline crossings, or some brief statement of informal policy.

Replies, with many well documented, were received from 44 states. The subcommittee (Edwin H. Jones, A. M. ASCE, Edward F. Kauffman, and R. Robinson Rowe, F. ASCE, Chairman) presented its findings to the full committee on January 23, 1958, in a memorandum (14 pages) which will be designated herein as Report A.

Subsequently, the documentary material was abstracted and arranged in topical order by Rowe, assisted by W. Forrest Johnson, M. ASCE and Nicholas A. Gust, M. ASCE. The memorandum (64 pages) entitled "Abstracts of Survey, State Policy and Practice on Highway Pipeline Crossings" was made available to this committee and will be cited as Report B.

Under date of September 16, 1958, the American Water Works Association initiated an inquiry through its representatives in the several states on its Highway Legislation Committee asking, inter alia, what restrictions had been imposed by each state on design and methods of installation of new water mains along or under new highways. Replies were summarized in a memorandum (30 pages) distributed January 6, 1959 by Harry E. Jordan, Aff. ASCE, Secretary of AWWA. Copy was made available to the chairman of this committee and will be cited as Report C.

TOPICS

For ready reference and further review, the survey citations with the analysis and findings of the committee will be combined in topical form, in the folowing order:

a. Bury, or depth of cover;
b. bedding and backfill;
c. encasement and allied protection;
d. vents;
e. jacking and boring;

f. hazardous transmittants;
g. road classification;
h. loads, stress, and deflection; and
i. location.

BURY, OR DEPTH OF COVER

Bury is defined as the vertical distance from top of pipe to a specified surface. A protective coating is considered part of the pipe. If the carrier is encased, bury is measured from top of the casing. For pipes installed in trenches, bury is the depth of cover. Commonly specified surfaces are the top of pavement, the natural ground, the bottom of a borrow ditch, or the invert or flow line of drainage ditches.

Table 1 shows the practice in 25 states as derived from Report A, with some revision dictated by Report B. The number of items (41) exceeds the number of replies because some states specify bury with respect to more than one surface. One graduates bury to pipe diameter. Several require 1 ft or $1\frac{1}{2}$ ft more bury for high-pressure fuel lines than for aqueducts. Two require water lines to be buried below frost hazard. One relaxes the bury for high groundwater or rock foundation.

TABLE 1.—MINIMUM BURY REQUIRED IN 25 STATES

Bury, in feet	Number Specifying Measurement From		
	Pavement	Ground	Ditch
1.5		2	3
2	4	1	2
2.5	4	1	4
3	7	1	6
4	3		
4.5	1		1
5	1		

In analysis of this range of minimum bury, it was realized that some states may use low-standard roads as a base and not permit the same minimum bury on high-standard roads, whereas others base their practice on high-standard roads and permit variances for lesser roads. Hence the "basic road" may range from oilcake-at-grassroots up to Interstate.

Except for roads of lowest standard, the highway must be considered an earth structure, with an elasto-plastic pavement supported by substructure of base, subbase, and compacted earth, each meeting definite specifications for quality and integrity. Combined thickness of pavement, base and subbase is of the order of 2 ft to 3 ft. Pipe must be excluded from this zone, with margin for overbreaking of holes bored for jacked pipelines, or development of an earth arch over entrenched flexible pipes. Loss of integrity will downgrade the pavement, increasing impact and hence inducing progressive subsidence, fracturing of the pavement slab, or both.

Acquisition of right of way presumes current or ultimate use of all of it for highway purposes. Outside the roadway prism, use is not always restricted to the surface, but may go below for emergency borrow, for drainage ditching, for erosion control, for control of noxious weeds, for signal cables in conduit, or for landscaping. Encroaching pipelines have proved quite vulnerable to mechanized operations for such purposes and should be located safely below the surface.

The critical requirement for bury is referenced to ditch grade. Here it must be foreseen that artificial channels may degrade by scour, or be degraded artificially to increase capacity, or that maintenance against the growth of aquatic vegetation may subexcavate a deep root zone.

The hazard of frost in cold climates should be considered from two viewpoints. For one, frozen roadbed may greatly increase the impact load reaching the pipe. For the other, liquid transmittants may be frozen in the pipe and burst it so as to saturate the fill when it thaws.

With some consideration for other factors, such as low-standard or temporary roads, wet or rocky subsoils, and urban distribution lines, the committee adopted the following as a basic guide to good practice:

1. Grade of top of pipe within the highway right of way shall be established so as to provide minimum bury or cover depth as follows:

Under pavement surface	4 ft
Under other surfaces, including ditch	3 ft

2. For flexible pipe under pavement, minimum cover shall not be less than outside diameter of pipe.
3. Additional overfill may be required in northern latitudes to prevent freezing of liquid transmittants.
4. If lesser overfills are permitted on low-standard roads, it should be stipulated that permit may be revoked when such road is built to a higher standard.
5. Minimum cover in urban areas may be reduced to conform to local ordinances regulating grade of utilities, usually limited to distribution lines of small size and low pressure.
6. To avoid rock excavation or laying pipelines below permanent water table, pipe may be laid to higher grade and protected with casing or capping acceptable to the highway engineer.

BEDDING AND BACKFILL

In trench construction, bedding is the subgrade soil and its surface, as prepared to support the pipe. Backfill is the material refilling the rest of the trench, consisting of sidefill up to the level of top of pipe, and of overfill above that level. The latter may include restoration of surface soils or roadway materials.

Table 2 has been prepared from the abstracts of Report B, covering, with some simplification, the practice in 23 states. Bedding was generally neglected, this factor being more vital to the utility. Some states cover backfill in great detail and others with little or none. No doubt the latter elsewhere demand compliance with standard specifications for structural backfill around

pipe culverts. Table 2 is necessarily semi-statistical because of the variety of requirements.

From the highway viewpoint, the essentials are (1) restoration of the structural integrity of entrenched roadbed, (2) security of the pipe against deformation likely to cause leakage, and (3) assurance against drainage following the trench or being blocked by the backfill. Trenches under pavement are seldom permitted outside urban areas, so that we are concerned more with integrity of shoulders and embankment slopes. Details of some specifications must conform to local climate and soil. Bedding is more important for the larger pipes. Considering these and other obvious factors, the committee proposes these two guides to good practice:

7. Bedding to a depth of 12 in. or half the diameter of the pipe, whichever is least, shall consist of fine granular soil, free of lumps, clods, and cobbles,

TABLE 2.—BEDDING AND BACKFILL REQUIRED IN 23 STATES

Factor	Specification	States
Bedding	Displace rocky material	2
Sidefill	Granular	1
Backfill	Replace native material	12
	Selected material	5
	Suitable material	2
	Granular material	3
	Cement-stabilized soil	1
Lamination	6-in layers	12
	3- or 4- layers	2
	No mention	9
Moisture	As required for compaction	3
	Puddling allowed	2
	Puddling forbidden	3
Compaction	Use mechanical tampers	13
	Compact thoroly	6
	Compact to 95% as per AASHO T-99	2
	Compact to match surrounding soil	1
	Compact properly	1

graded to a firm but yielding surface without sudden change in bearing value. Unsuitable soils and rock ledges shall be subexcavated and replaced by imported material. For carriers laid without encasement, the bed will be shaped to fit the bottom of the pipe for 60% of its width.

8. Backfill shall be made in two stages, (a) sidefill to the level of the top of pipe, and (b) overfill to former surface grade. Sidefill shall consist of fine granular material laid in 6-in. layers, each consolidated by mechanical tamping and controlled addition of moisture, to a density of 95% as determined by AASHO Method T-99. Overfill shall be layered and consolidated to match the entrenched material in cohesion and compaction. Consolidation by saturation or ponding will not be permitted. For backfill of entrenched pavement, materials and methods of compaction shall be adapted to prompt restoration of traffic, specifying also additional cutback of base and surfacing and transitioning

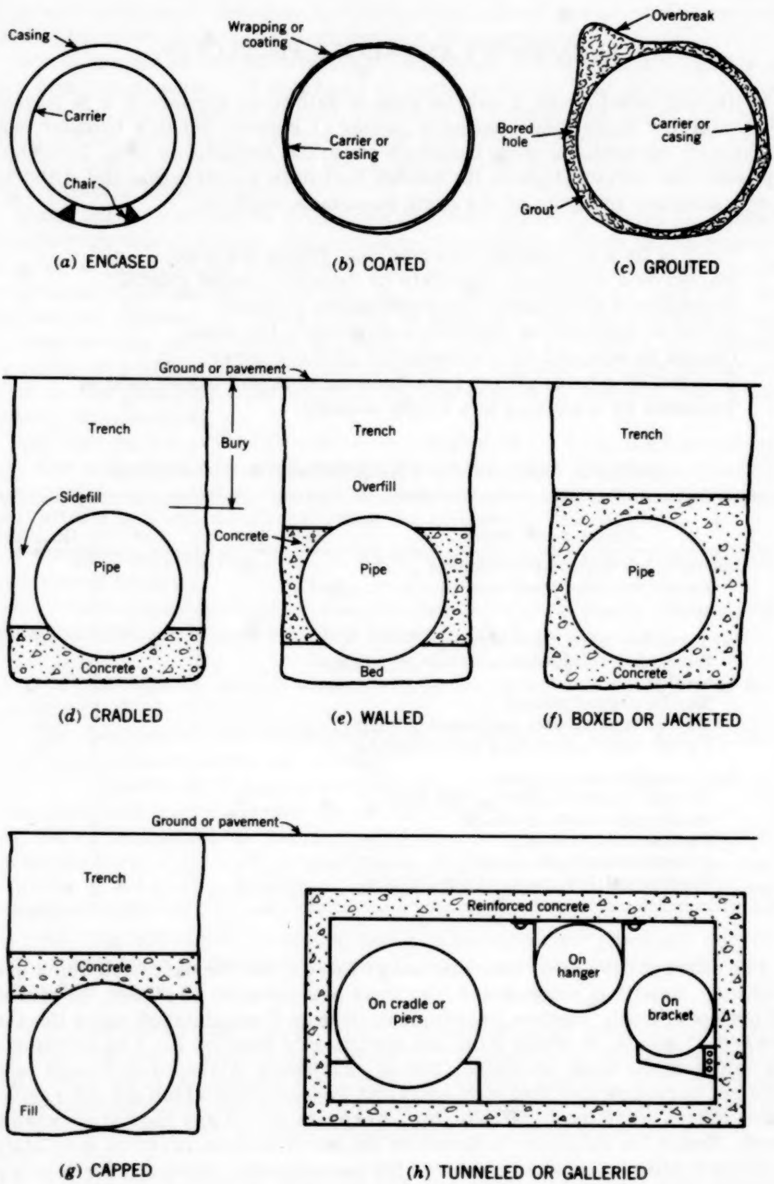

FIG. 1.—TERMINOLOGY FOR ENCASEMENT AND ALLIED PROTECTION

of trench shoulders to minimize the development of sag in grade of pavement over the trench.

ENCASEMENT AND ALLIED PROTECTION

In its narrowest sense, a carrier pipe is said to be encased if it is installed freely inside a larger pipe called a casing or sleeve, but in a broader sense encasement may include other complete or partial enclosures (Fig. 1) designed to protect the carrier, lighten its burden, facilitate its insertion and withdrawal, or guarantee integrity of the earth structure, such as:

Cradled by a continuous concrete seat fitting the pipe;
Walled by a continuous concrete or cement-treated sidefill;
Capped by a continuous concrete topping or slab;
Boxed or jacketed by concrete surrounding the pipe;
Coated or wrapped by a substantial girdling cover;
Grouted by mortar filling bore-hole annulus and overbreak; or
Tunneled by installing in a utility subway.

TABLE 3.—ENCASEMENT REQUIREMENT IN 43 STATES

Encasement factor	Yes	No	Qualified
Required for Interstate crossings	36	6	1
Except for reinforced concrete or wrapped steel			1
Required for other main highways	27	9	7
Except for reinforced concrete or wrapped steel pipe			1
May be capped instead			1
May be waived after engineering study			1
Except small pipe under low pressure			4
May consider other items:			
Excepts small copper or lead pipes	3		
Jacked pipe must be cased	1		
Excepts cast iron pipe	1		
Excepts lines in thorocut	1		
Prefers gallery (subway) for big pipe	2		

The surveys have been summarized in Table 3, but the data need some qualification. Report B emphasized fuel lines and covered 43 states, 16 of which did not specifically mention encasement. Report C emphasized water lines and covered 37 states, of which 9 did not specifically mention it. The combination has information from 46 states, that is, excluding Alaska and Hawaii which were not surveyed, and Massachusetts and Pennsylvania which did not respond. Three others were too indefinite for interpretation of any kind of encasement policy. Hence the summary is based on the fairly definite practice in 43 states.

Context often implied an objective for encasement. Dominant for Interstate highways was the facility for insertion, inspection, and replacement of carrier pipes without trespassing on restricted right of way. Correlative requirement

of vents expressed a concern over leakage of transmittants. The capping alternative suggests concern over the vulnerability of pipeline from subsurface highway operations. The tie-in with jacking reflects the doubt that protective coating survives the hazard of abrasion in the operation.

Not in context is the uncertainty of deflection and stress in a flexible carrier pipe compressed and deformed by earth pressure and laternately loaded with low and high internal pressure tending to ovalize and restore a circular shape. This phenomenon of "breathing" and design criteria for such loadings are very much in dispute. Also in dispute is a contention that encasement impairs cathodic protection.

These matters cannot be fully resolved from present knowledge. However, an arbitrary policy of requiring encasement for all crossings is too expensive, not only to the pipeliner crossing a highway, but to the public when a highway crosses an existing pipeline. Neither is it prudent, considering past experience and current appraisal of future hazard, to waive all encasement requirements. An intermediate policy should concede the highway engineer's responsibility for safety of traffic and structural integrity of roadway, placing the burden of proof on the pipeliner if he contends for any particular location that encasement is unnecessary.

Although such a policy should never require proof from the highway engineer that encasement is necessary, he should not specify it without reason. As an approach to a prudent but logical standard, the committee expresses its qualitative appraisal of rational bases for encasement as follows:

9. Widely varying practices in the several states reflect a lack of rational definition of hazards.

10. There are compelling reasons for requiring encasement of all pipelines under Interstate and limited-access highways, such as:

(a) Leakage of liquids would destroy the structural integrity of the roadbed;

(b) Leakage of gas would permeate the earth structure, risking fire or precautionary detouring of traffic;

(c) Stipulations that pipeline operations will never interfere with free movement of traffic are not always enforceable;

(d) The question of interference concerns not only the pavement but restriction against surface operations, including parking of service vehicles, in median, on shoulders, or anywhere between control-of-access lines;

(e) The warrant is so strong that highway agencies generally encase or protect in an equivalent manner all pipelines it crosses by such high-standard roads.

11. Encasement should be required for jacked or bored installations of coated pipe unless there is positive assurance against damage to protective coatings.

12. Regardless of access restriction the highway agency, in its discretion, may require (and certainly should consider) encasement of all lines under heavily traveled roads, and of lines transmitting dangerous substances under any road.

13. Encasement may be required for any pipeline located with impaired clearances or near unusual hazards such as high-tension power lines, flood channels, subsiding ground, etc.

14. Rigid encasement or capping should be required if support of pavement would otherwise be impaired by flexible pipe.

15. Encasement may be required to anticipate future widening or other alteration of highway facilities.

VENTS

Vents are appurtenances to casings by which fluids between carrier and casing may be inspected, sampled, exhausted, or evacuated. The fluids may be leakage from the carrier within or the soil without, or atmospheric vapor and condensate, or decomposition products of pipes and coatings. Liquids and heavy gases can be vented by gravity drains; light gases are exhausted thru risers or standpipes projecting above the ground surface.

From Reports A and B, of 27 states that required casings, only 14 mentioned vents. Table 4 summarizes their specifications.

TABLE 4.—CASING-VENT REQUIREMENT IN 14 STATES

Factor	Number
Vents required on all casings	6
only on fuel lines	8
Specified maximum spacing (100 ft or 150 ft)	3
Specified minimum diameter, $1\frac{1}{2}$ in. or 2 in.	4
3 in. or 4 in.	2
Located standpipe, at right-of-way line	9
at fence line	1
Specified height of standpipe at 4 ft	1

The committee has not completed consideration of these factors, but has noted the greater importance of venting fuel lines and locating standpipes at or near the right-of-way line or fence line. Long crossings require a vent at each end. The facility to detect leakage may be important. The disposal of vented liquids and heavy gases should be restricted.

JACKING OR BORING

All states have some sort of restriction against entrenchment of pavements, specifying the alternative by such procedures as jacking, boring, pushing, tunneling, or augering. Each of these procedures has some variety in detail of operation, the most significant being the division of boring into dry boring and wet boring.

Requirements of the states are of two sorts: (1) entrenchment is forbidden, and (2) control of the operation to guard against impairment of the earth structure under pavement and shoulders.

Reports B and C have been combined and summarized in Table 5, from which it will appear that highway pavements may seldom be cut, execptions

being limited to situations where boring or jacking is impractical. However, there are few restrictions on alternative methods and surprisingly little specification of remedial work to backfill oversize holes and overbreaks. The committee is giving further study to need for such specifications.

With respect to Interstate highways, it is pertinent to quote from Item 5C of "A policy on the accommodation of utilities on the national system of Interstate and defense highways" adopted July 30, 1959 by the American Association of State Highway Officials:

> Utilities crossing underground below the roadways of Interstate highways shall be . . . so installed as to virtually preclude any necessity for disturbing the roadways to perform maintenance or expansion operations . . . Manholes and other points of access . . . may be permitted . . . only when they are located . . . where they can be serviced or maintained without access from the through-traffic roadways or ramps.

HAZARDOUS TRANSMITTANTS

Practically every state for which detailed information was received had some differential in its practice derived from relative hazard of the transmittants, but lines of demarcation between ordinary and extraordinary hazards were so varied as to defy tabulation.

TABLE 5.—JACKING OR BORING REQUIREMENTS IN 46 STATES

Factor	Number
No cutting of Interstate pavement	46
Cutting of other major highways, forbidden	35
sometimes	2
allowed	2
unspecified	7
Jacking required, to shoulder	4
to shoulder plus 2 ft	6
to edge pavement plus 14 in.	1
unspecified	35
Boring restricted to pipe size	4
to pipe diameter plus 1 in.	1
to cohesive soils	1
to dry process	3
Backfill with lean dry-mix concrete	1
Exception made for ledge rock	7
for sewers	1

High Pressure.—The lower limit of "high pressure" ranged from 5 to 300 psig. There is no upper limit, but 1500 psig has been carried under highways. Special requirements included encasement, hydrostatic testing to 50% excess, shut-off valves handy, markers, and isolation from structures.

Flammables.—Flammables were differentiated as gas, liquids, and liquified gas. Except for distribution lines, requirements were generally related to

working pressure. Some called for compliance with ASA Code B31. Encasement and isolation were the most common calls.

Corrosives.—When corrosives were mentioned, encasement and periodic inspection were called for, usually with the obvious specification of a nonreactive pipe wall.

High Tension.—Although not specifically asked for, two replies noted limits of line voltage for underground cables in conduit and required shielding and isolation from structures and other pipelines.

The committee plans further survey of practice and experience with hazardous transmittants. From spot checks, it is concerned that highway agencies are not fully advised of operational changes increasing hazard, such as increasing the working pressure, or converting a line to carry L-P gas. For the latter, it is concerned that leakage of butane and propane is not easily detected and, being heavy gases, they collect in low places.

ROAD CLASSIFICATION

Any approach to codification of minimum requirements must depend on a rational classification of roads by which certain factors may be differentiated. The following classes were noted in Reports B and C:

County	High-type	Paved	Surfaced
Dual-lane	Interstate	Primary	Trunk
Expressway	Lightly-traveled	Rural	Unimproved
Freeway	Limited-access	Secondary	United States
Hard-surfaced	Low-type	State	Urban

Seven states referred to ASA Standard B31.8, which establishes design and test factors based on a classification of roads by location. There are four classes of location with differentiation of road standard in three of them, making seven classes and subclasses, briefly as follows:

Uninhabited or farm land	1a. Unimproved	1b. Paved
Suburban fringe	2a. Unimproved	2b. Paved
Urban, 10% built-up	3a. Unimproved	3b. Paved
Urban, multistory	4. All streets	

These are not adaptable to highways, primarily because the location classes measure hazard by environment and not by traffic. Based more on utility of the highway and its traffic, the committee has prepared the following, for discussion only and without conclusions:

Expressway	Cutting and access forbidden
Arterial	Surface operations restricted
Secondary	Much less restriction
Urban	Way fully developed; utility franchised
Rural	Minimum restriction
Temporary	No specific restriction

LOADS, STRESS, AND DEFLECTION

Except by reference to ASA B31.8 or local codes, and indirect requests for adequate support of pavement, the surveys and reports found no requirement

specifying design loads, or limiting stress or deflection. Presumably the pipeliner is responsible for this phase of design. However, the highway engineer is better informed on live loads which may contribute to stress and deflection of a pipe, and the deflection of pipe that may be allowed without damage or impairment of pavement.

Live load, for example, is not simply the legal load, for extra-legal loads operate under special permit and illegal loads of much greater weight are intercepted by patrols quite frequently. During highway construction, earthmoving equipment may impose loads 3 or 4 times the legal limit without help from pavement to distribute it.

Depending on diameter of pipe and its bury, the critical live load may be the dual wheel, the single axle, or the tandem axle. In the 50 states, statutory limits for wheel loads range from 9,000 lb to 12,000 lb and single axles from 18,000 lb to 24,000 lb. For tandem axles the statutory limit ranges from 30,000 lb to 40,000 lb, but statutory tolerance for enforcement effectively raises this to the range 31,500 lb to 44,000 lb. In consideration of the policy for special permits, the loads in Table 6 have been proposed for pipeline design, with the highway engineer appraising the current and prospective duty of the road.

With respect to stress and deflection, it should be conceded that highway codes need not go beyond highway responsibility for integrity of the roadbed and earth structure, and for safety of traffic. In a casing, stress levels are of interest only as a means of computing deflection or predicting collapse, but in an uncased carrier, the combination of stress with deflection may develop local secondary stress and strain so as to rupture it, causing leakage or explosion. For a carrier inside a casing, stress and deflection do not affect integrity of roadbed, leakage is exhausted and detected at vents, and hazard of explosion has the casing as a "second line of defense;" hence highways need not add any special requirement for such carriers beyond the standing requirements of regulatory agencies.

TABLE 6.—VEHICULAR LIVE LOADS FOR PIPELINE DESIGN

Live load	Light-duty road	Heavy-duty road
Dual wheel	10,000	15,000
Single axle	18,000	27,000
Tandem axle	32,000	48,000

Practically, this limits highway requirements to pipes in contact with and a component part of the earth structure supporting the roadway. When these are rigid pipes, ovalizing or diametric deflection is small and negligible in its effect on pavement grade, but longitudinal deflection due to varied subsidence of foundation soils may articulate the pipeline at its joints, with hazard of leakage. On the other hand, flexible pipes conform readily to ordinary longitudinal deflection, but may threaten pavement support by large diametric deflection. The latter may be sensitive to alternations of internal pressure, from zero during purges up to working pressures as high as 1,500 psig.

Many designs will be analogous to highway culverts, so that requirements and supervision can be referenced to standard specifications. For the combination of external loads with internal pressures on flexible pipes, the com-

mittee is awaiting findings of the Research Council of the Committee on Pipeline Crossings of Railroads and Highways of the Pipeline Division.

LOCATION

Report B contains many indefinite specifications affecting or guiding location of crossings, some of which warrant review because of contradictory principles or questions of interpretation.

Of considerable importance is the requirement in many states that the crossing be normal to the highway, and in many others that it be as nearly so as practical. Where a new pipeline crosses an old highway at an angle, the rule would add two bends to the line (Fig. 2). Where an Interstate crosses an old pipeline at an angle, the rule would add three bends and considerable length. Thus if the angle was 30° across a 200-ft right of way, a 400-ft section of pipeline would be replaced by (a) a 30° bend, (b) 346 ft of parallel line, (c) a 90° bend, (d) 200 ft of encased carrier, and (e) a 60° bend.

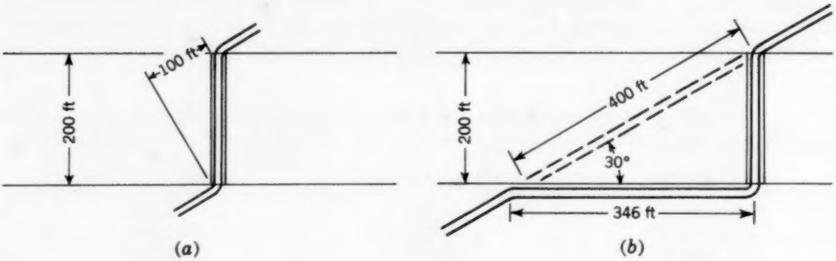

FIG. 2.—UNECONOMIC RESULT OF DEMAND FOR NORMAL CROSSINGS: (a) NEW PIPELINE MAKING NORMAL CROSSING OF OLD HIGHWAY WITH ADDITION OF TWO BENDS AND 100 FT OF PIPE; (b) OLD PIPELINE RELOCATED NORMAL TO NEW HIGHWAY WITH ADDITION OF THREE BANDS, 146 FT OF PIPE, AND PARALLEL EASEMENT

For the latter, it might be cheaper to encase the entire 400 ft of old pipe falling in the right of way. When forced to the new line, the status of the 346-ft parallel raises some questions. Is it part of a "crossing" and hence permitted on the right of way? If so, must it be encased? Or is it a parallel location and hence excluded from the right of way?

Also important were references to structures. Some states forbid all crossings near structures, one restricting proximity to 100 ft. Others let pipelines hang under or within separation structures. Some allow restricted use of existing culverts and encourage the construction of utility culverts for one large or several small lines. Except for Interstate highways with definite restrictions, the practice is far from uniform.

In the committee's opinion, the crossing angle should be limited only by economics. The other problems warrant further survey and study.

CONCLUSIONS

Tables 1 to 5 and other text support a general finding of wide variance in highway pipeline-crossing practice. The 15 particular findings have been designated serially to invite and coordinate comment. The last six topics are still in review and comment is invited on opinions expressed or implied therein, supported if possible by factual data or rational analysis. Most welcome is advice to the committee of other topics needing attention or coordination, related to or bearing on highway responsibility for pipeline design or construction.

This progress report is concluded with a statement of the principle of reciprocation which is almost axiomatic: Requirements for pipelines crossing highways should coincide with requirements for highways crossing pipelines.

Respectively submitted,

Hubert H. Brown
Douglas B. Fugate
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Committee on Pipeline Crossings,
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DISCUSSION

HIGH TEMPERATURE EFFECTS ON BITUMINOUS MIXES[a]

Closure by William H. Gotolski

WILLIAM H. GOTOLSKI,[21] M. ASCE.—The writer is grateful to Messers. Gallaway, Woodward, Lottman, Hveem, and McRae for contributing their thinking to a subject that, today, is a controversial but interesting phase of bituminous mix design. Their pertinent discussions add to the value of the paper and raise some points worthy of further comment. Additional background must be given in order to clarify some of the points raised. First, the Pennsylvania Department of Highways raised the question of the effect of excessive temperatures on asphaltic concrete mixes. The study was undertaken using asphalt cement from the same source used by the department. Secondly, the study was limited to a laboratory investigation and the various test equipment available to the writer at that time.

The Marshall method, the Hveem stabilometer, the penetration, and ductility tests were used because of the availability of such equipment. With the use of these devices and the use of the Brown, Sparks, and Larsen criteria, it was not the intent of the writer to imply that all asphalts may be exposed to 375°F without detrimental effects. There have been several cases wherein mix temperatures in excess of 325°F have been used successfully. One case was the facing of upstream and downstream faces of an earth dam. This job was concerned with the facing of 30° slopes on the Montgomery Dam in Colorado. The temperature used here was 375°F. Woodward has supplied data indicating higher aggregate temperature results in a satisfactory product (Tables 10 through 13). Further, in correspondence between Woodward and the writer (correspondence dated November 1, 1960), Woodward presented data from two additional projects that indicate the same. However, the writer is in agreement with Gallaway and Hveem that 375°F may be questionable and the writer again wishes to emphasize that it was not the intent to recommend raising the temperature to 375°F for all asphalts, but that it could be used in the case of some asphalts. It was recognized that variability of materials exist. This was indicated when the writer stated materials used in the investigation were obtained from a single source. The reader must then keep in mind that conclusions drawn are based on such conditions and may not be used to blanket the field.

In response to further questions it may be stated that extractions were made on sixteen randomly selected specimens. A highway department representative reported that their extraction results essentially agreed with "When this asphalt is sprayed into a pugmill with aggregate at 375°F its penetration value would drop to about 72." Effective film thicknesses, unfortunately, were not investigated.

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[a] September 1960, by William H. Gotolski (Proc. Paper 2592).

[21] Assoc. Prof. of Civ. Engrg., Pennsylvania State Univ., University Park, Pa.

Some researchers believe the penetration test, the Loss-on-Heat test, and the ductility test are the only needed tests in specifying good durable asphalt cements.[22] Others[23] feel that the BPR thin-film oven test be used on asphalt films corresponding to the thicknesses in actual mixes (under 4 microns). The writer believes in modern methods and tools but was limited by equipment to the use of the penetrometer. It is firmly believed that kinematic viscosity would be an even better specification to use in measuring hardening or durability of asphalt cements. Another possibility may be the low temperature-low speed ductility test mentioned by Lottman.

On February 22, 1961, the writer participated in a study with Ara Shrestinian concerning temperatures in bituminous mixes. Based on experiences of Shrestinian the following points were brought out. It was indicated that the maximum difference in temperature between asphalt and aggregate should not exceed 25°F. For example, if an aggregate were heated to 400°F and then combined with an asphalt heated to 225°F there would be a tendency for the asphalt to crystallize when the film hit the hot aggregate surface. Shrestinian expressed his opinion that 370°F was the turning point. He further stated that there are some aggregates which coat better at higher temperatures.

The relationship of time with change in asphalt properties was formulated by A. B. Brown, J. W. Sparks, and O. Larsen.[24] The relationship derived is a rectilinear hyperbola. McRae indicates a satisfactory life expectancy of 18 yr would be more appropriate. The writer concurs. Nine years of life for a pavement seems rather short. It was the intent of the writer to emphasize an accumulation of data over 9 yr or 10 yr period would give an indication as to whether the pavement would be alive for an 18 yr to 20 yr period. Assuming Eq. 3 is correct, the penetration of the asphalt would remain above the limiting value of 33 even at the age of 18 yr. This is based on the constants a and b as evaluated by the writer ($a = 0.03$ and $b = 0.026$). Continuous measurements would verify or disprove the assumption that a rectilinear hyperbolic relationship exists between time and penetration, ductility, and softening point. Data accumulated from the earlier life periods are better than those of later life periods.[24]

The writer is interested in Hveem's reference to the Zaca-Wigmore experimental project in California and acknowledges the fact that Brown, Sparks, and Larsen criteria should be studied further.

The Pennsylvania Department of Highways is developing a set of Marshall Standards for local materials. The writer believes that their compactive effort will compare favorably to the 50 blows per face as per the study made. In talking with local contractors it was their feeling that a 6% asphalt content would result in a mix which would be incapable of holding its shape or even being formed into a Marshall specimen. From the study it was found that Marshall specimens could be formed and reasonable stability and flow values ob-

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22 "Asphalt Volatility and Weathering Tests," by R. G. Clark, Proceedings, Assn. of Asphalt Paving Technologists, Vol. 25, 1956, p. 417.

23 "A Study of Some Factors Influencing the Weathering of Paving Asphalts," by B. A. Vallerga, C. L. Monismith, and K. Granthem, Proceedings, Assn. of Asphalt Paving Technologists, Vol. 26, 1957, p. 126.

24 "Rate of Change of Softening Point, Penetration, and Ductility of Asphalt in Bituminous Pavement," by A. B. Brown, J. W. Sparks, and O. Larsen, Proceedings, Assn. of Asphalt Paving Technologists, Vol. 26, 1957, p. 66.

tained. Department of Highway Specifications[25] limit asphalt content, percentage by weight, to 6-12 for an FJ-1 mix. The original study[26] selected the value of 6.0% asphalt and the two gradations to determine the actual effects of gradation on the Marshall properties of two of the most used surfaces in Pennsylvania (statewide basis, 1960, about 97% of resurfacing consisted of ID-2 and FJ-1). It was felt that with the void characteristics of the particular mix studied (FJ-1), the resulting pavement would ravel and break up. Using the proper asphalt content for the particular gradation used, the resulting pavement would perform satisfactorily.

The writer acknowledges the fact that Conclusion 2 may be based on too limited data and is indebted to McRae for his reference to the work done by Verdi Adam.

At the time of the study of high temperatures, the question was raised concerning the economies of operation. The writer appreciates the raising of that point by Lottman. It is further appreciated that Lottman presents advantages and disadvantages of heating aggregates to 375°F.

From the study raised, it appears that some advantages can be gained by heating aggregates to 375°F and that the resulting mixes are still satisfactory. It is also apparent that there are also disadvantages to this raised temperature treatment.

Where does the writer's study and the thoughtful commentaries of the discussers eventually lead us to? The indication is that further research is necessary concerning this controversial area of bituminous mix design.

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25 "Specifications for Plant Mix," Dept. of Highways, Commonwealth of Pa., Bulletin 27, 1954, Harrisburg, Pa.

26 "Effects of High Temperatures on the Properties of Asphalt-Aggregate Mixes and A New Concept in Mix Design," by W. H. Gotolski, thesis presented to the Pennsylvania State Univ. at University Park, in June, 1959, as partial fulfilment for the requirements for the degree of Doctor of Philosophy.

LTS DESIGN OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT[a]

Discussion by I. J. Taylor

I. J. TAYLOR.[10]—This is a timely and well prepared paper on a subject that should be of interest to everyone responsible for the design and construction of our highways. A load-temperature-shrinkage concept of continuous pavement seems sound and the authors have developed their design criteria with convincing logic. The fact that the Texas Highway Department has been successful in the construction of this unique type of pavement should add emphasis and interest in their report.

Most analytical approaches to continuous pavement design result in recommendations for the use of approximately 0.7% longitudinal reinforcing steel with a yield point of 60,000 psi if 4,000 psi compressive strength concrete is used. These values satisfy the concept that the ultimate tensile strength of the concrete must not exceed the yield strength of the reinforcement steel in a given pavement cross-section. While it is believed that this concept is accurate, some explanation is needed for the satisfactory performance of several existing continuous pavements with only 0.5% reinforcement.

As the authors indicate, localized tensioned areas develop in the concrete because the longitudinal reinforcement resists the stress and strains of the curing shrinkage. An uneven stress pattern is "cured" into the concrete, causing transverse planes of weakness and reducing the ultimate longitudinal tensile strength of the total pavement. When thermal contraction influences both the reinforcement and the concrete, the concrete can crack at these transverse planes of weakness when the tension stress is only slightly increased. Tests at the Fritz Engineering Laboratory of Lehigh University, Bethlehem, Pa., have shown that this shrinkage-temperature effect may cause a 20% reduction in the normal tensile strength of the concrete used in continuously reinforced concrete structures.

Another factor to be considered is the general practice of steel manufacturers to supply reinforcement with a higher yield than the specified minimum. The average yield of the reinforcement supplied for two recent continuous pavement projects in Pennsylvania exceeded the specified minimum by approximately 12%.

Because recommendations for optimum design are based on the relative strengths of the reinforcement and the concrete, the combined effect of stronger reinforcement and weaker concrete can result in a pavement that is overdesigned by as much as 30%. This would indicate that the longitudinal reinforcement could be lowered to 0.5% and still meet the optimum design requirements.

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[a] December 1960, by B. J. McCullough and W. B. Ledbetter (Proc. Paper 2677).

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In their conclusions, the authors recommend consideration of the construction season when determining the percentage of reinforcing steel to be used. This seems to unnecessarily complicate the design and the construction scheduling and does not appear to be justified if the only purpose is to establish a selected crack pattern.

A high temperature during the construction period should not result in higher stress or wider cracks during the cold weather season. A pavement constructed in hot weather will certainly be subjected to more thermal contraction and more longitudinal straining, but this should only increase the crack frequency. If adequate reinforcement is present, new cracks will occur as the ultimate tensile strength of the concrete is reached. These new cracks will open a width which is limited by the bond strength and strain characteristics of the reinforcing steel. Because maximum stress is limited by the ultimate tensile strength of the concrete and crack width is limited by bond and steel characteristics, the number of cracks in a pavement indicates only the maximum strain that has occurred since its construction. Maximum stress and crack width are controlled by pavement design and therefore should not be affected by construction temperatures. It seems that the control of transverse crack width should be a major design objective and that the crack frequency should be permitted to vary with the amount of encountered thermal straining.

Experiences with 7-in. thick experimental pavements in Pennsylvania have been discouraging. A 2,000-ft long dual lane section constructed in 1957 had to be torn out and replaced in 1960, and it is expected that other 7-in. thick sections may require extensive repairs or replacement in the near future. Some of this distress was due to unsatisfactory road bed conditions and heavy traffic loads, but the increased flexibility of the thinner pavement slab has certainly contributed to the failures. Longitudinal flexing of the pavement under heavy wheel loads concurrent with constantly changing temperature induced stress has caused rapid deterioration at transverse cracks.

There appears to be a need for further investigation to determine the feasibility of the direct application of Westergaard's theoretical equation in the design of continuously reinforced pavements. The construction of more 7-in. pavements will increase the available knowledge of their performance and will be of considerable interest to those invovled in continuous pavement research.

While this analysis has emphasized a few minor disagreements with statements made by the authors, it is not intended to criticize their basic concepts or their excellent coverage of the factors to be considered in the design of continuous pavements.

PREFABRICATED REDUCERS AS ENTRANCES FOR PIPE CULVERTS[a]

Discussion by Herbert G. Bossy

HERBERT G. BOSSY,[6] F. ASCE.—Extensive investigations of the performance of enlarged inlets tapering to join conventional circular pipe culverts have recently been completed. A report of the laboratory investigation,[7] made with 5.5-in., 12-in. and 30-in. diameter models, has been submitted to the Bureau of Public Roads, United States Dept. of Commerce (BPR). On the basis of these investigations, the writer can find no justification for assuming that a tapered inlet (or reducer) will cause a culvert barrel on a steep slope to flow full with resultant control at the outlet in all or even a majority of conditions. The author in his conclusions expresses an opposite opinion in stating that the reducer entrance will permit effective use of a subatmospheric pressure at the inlet. However, his argument is weakened by the statement that the extent of this effective pressure could not be determined.

Culverts with sufficient fall of the flow line to produce a zone of subatmospheric pressure at the inlet as a result of flowing full would appear to be economic solutions for the culvert design problem. However, such an approach should not be used unless the reduced pressure can be reliably protected against ventilation by a vortex over the inlet.

A zone of subatmospheric pressure below a culvert inlet can be created either by entrainment of air at a surface of flow exposed to air in a separation cavity, or by full conduit flow. In the latter case control is at the outlet and the rise of the pressure line brought about by resistance losses in the barrel is not sufficient to produce a positive pressure in the inlet zone. Priming of small scale model culverts with tapered inlets originates from the first condition and eventually reaches the second. It is this final result the author appears to rely on in stating his conclusions. However, experience with a wide variety of culvert models with many forms of inlet enlargement has demonstrated that maintenance of subatmospheric pressure is extremely unreliable as an effective means for reducing the depth of headwater. The effects of a vortex over the inlet in dissipating any subatmospheric pressure formed in a zone of separation of flow from the boundaries cannot be scaled up from small model sizes by application of a simple Froude law.

It will be difficult to apply the equations of the paper to culvert inlets since depth of flow is unknown, and as a consequence velocity head is also unknown. Therefore, any manipulation leading to a supposed value of pressure reduction cannot be valid. It is, of course, possible to use inlet face dimensions as a

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a March 1961, by Harvey G. Aronson (Proc. Paper 2766).

6 Highway Research Engr., Div. of Hydr. Research, Bur. of Pub. Rds., Washington 25, D. C.

7 "Hydraulics of Improved Inlet Structures for Pipe Culverts," by John L. French, Natl. Bur. of Standards Report 7178, August, 1961.

base for an energy equation, but experimentally determined pressure terms must be introduced to account for the effects of the curvilinear flow which actually occurs. Similarly, discharge coefficients for various geometric forms must be determined.

For example, consider an equation applicable to control at the throat of a tapered inlet. Optimum performance of a well-desgined inlet requires that the throat section control the rate of flow, since the more costly portion of the culvert will be the barrel and the throat area is necessarily the same as that of the barrel. The inlet should be designed with ample face area to assure that the throat section, rather than the face, controls the flow. With sufficient submergence of the inlet to attain full flow in the taper immediately above the throat, the throat section will control the energy requirement by contracting the flow to an area somewhat less than that of the throat, or barrel. For this condition the equation

$$\frac{H_h}{D_2} = \frac{(4/\pi)^2\ Q^2}{2g\ C_t^2\ D_2^5} + \frac{y_2}{D_2} + \frac{p_2}{\rho\ g\ D_2} - S\left(\frac{L_{1-2} + 0.5\ D_2}{D_2}\right) \quad \ldots\ldots (18)$$

will apply.

The author's nomenclature is used with these additions: y is an effective pressure term corresponding approximately to a depth with hydrostatic pressure distribution in the flow prism; p denotes the intensity of air pressure, relative to atmospheric, acting on the free surface of the contracted flow at and just beyond the throat; ρ refers to the mass density of water; C_t describes the inlet throat discharge coefficient (0.90 or more for smooth wall inlets with taper angles 12° or less) and L_{1-2} is the axial length of the tapered inlet. The subscripts refer to the control sections indicated in Fig. 2. The dimension, inlet length plus 0.5 D times S, is an empirical value to compensate for barrel slope effects and thus to maintain y_2 constant for a given inlet form. The air pressure term is normally small and negative. Test data reveal that it approaches zero under any condition leading to maintenance of a vortex for significant time intervals. It has also been demonstrated that the negative values often measured in small models do not scale up at larger sizes.

The inlet throat control equation given in Eq. 18 may be solved by use of experimental determinations of C_t and y/D. Of course, use of the air pressure term as zero instead of a negative value gives maximum head for a given Q and barrel size, and thereby a conservative design.

A tapered-inlet culvert operating in inlet control because of a steep slope will have a satisfactorily high capacity, as is indicated by the above equation with C_t of 0.90. Even better performance is possible, because C_t may reach 0.94 with the best inlet details. For comparison, the discharge coefficient for a square-edged inlet without enlargement is 0.625, also based on barrel area.

It is necessary to determine whether a culvert will operate in inlet throat control, previously stated, or will instead fill because of the high rate of flow and a limited slope. Whether inlet or outlet control (full flow) prevails is readily determined by comparing inlet control head to outlet control head computed for full flow by the equation

$$\frac{H_h}{D_2} = \frac{h_3}{D_2} + \frac{L}{D_2}\left(\frac{4^{4/3}\ n^2\ (4/\pi)^2}{1.486^2\ D_2^{1/3}}\ \frac{Q^2}{D_2^5}\right) + (1 + k_e)\ \frac{(4/\pi)^2}{2\ g}\ \frac{Q^2}{D_2^5} - \frac{S\ L}{D_2} \quad \ldots (19)$$

in which D_2 is taken as equal to D_3.

The greater headwater depth will indicate the type of flow in the culvert and thus the design condition. The only new term here is h_3/D_2, the elevation of the mean pressure line above the flow line at the outlet measured in terms of D_2. This factor varies with the discharge rate $Q/D^{5/2}$, but for conservative design purposes may be assumed to be 1.0 for rectangular culverts or 0.95 for pipe, pipe-arch, or other barrel sections with an arched soffit.

The author advises that caution be used in applying the methods of the paper since these are based on small models. The writer would join in this recommendation and extend it to avoidance of all methods based on an assumption that subatmospheric pressures found in small scale model culverts with any degree of inlet improvement will scale up to equivalent performance in culverts of normal highway size.

In addition, the culvert inlet control nomograph referred to cannot be applied to the inlet face area of a tapered inlet except as an approximate check to determine that throat control will govern. Also the nomograph will give a considerable error in headwater depth if applied to the throat section of a tapered inlet. The headwater so determined will be too great since the inlet face discharge coefficients on which the various nomograph scales are based are significantly less than the characteristic value of 0.9 for properly designed smooth-wall tapered inlets.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2703 is identified as 2703(ST1) which indicates that the paper is contained in the first issue of the Journal of the Structural Division during 1961.

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c. Discussion of several papers, grouped by divisions.

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